

# **LASER MARKING IN THE AEROSPACE INDUSTRY**

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## **Abstract**

The primary reasons to identify aircraft parts is to ensure that the proper parts are installed in the right location and to be able to relate individual parts to their respective historical documentation. These requirements are clearly defined in Federal Aviation Administration (FAA) regulations and manufacturer marking specifications. Recent aircraft catastrophes related to counterfeit parts, however, have resulted in rethinking how part identification numbers are applied to parts and controlled during operational use. The greatest concerns are how to:

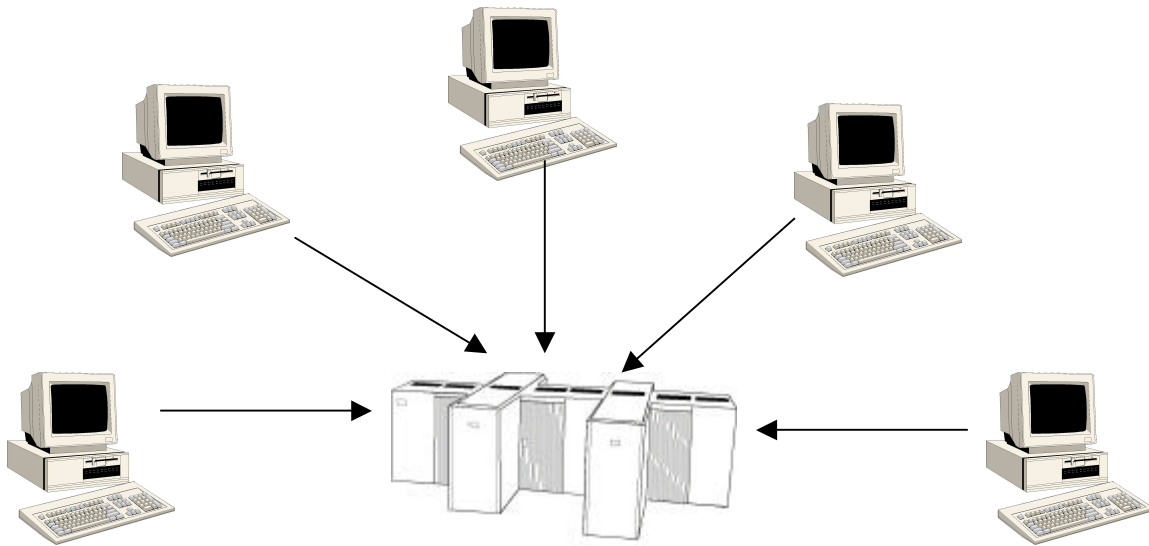
- Accumulate part use history in a central or national database
- Develop a means to automatically capture part identification to reduce transposition errors in the historical documentation
- Eliminate human error.
- Develop means to identify parts too small to accommodate human readable markings
- Reduce safety risks associated with direct part marking

A number of different organizations have united to solve these issues and have made significant progress.

## **Central Databasing**

The need to accumulate part history in a central or national database is being addressed by the FAA, Department of Transportation (DoT) and the Aircraft Transportation Association (ATA). The three are providing guidance to an industry forum responsible for developing a central aircraft parts database known as SPEC 2000.

SPEC 2000 (web site address: <http://www.spec2000.com>) provides a specification of standard formats to exchange information between airlines and their suppliers. It is specifically tailored to airline industry needs for procurement and repair transactions for aircraft maintenance. Spec 2000 has been adopted by the international airlines and is recognized as the industry standard by a long list of participants around the world.

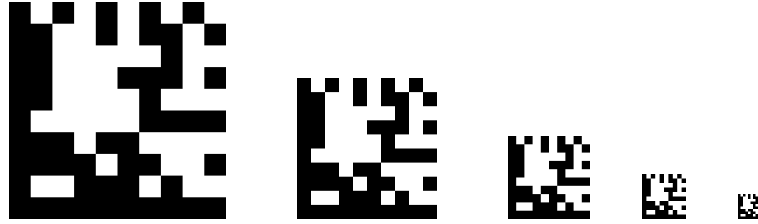


*Figure 1 – Central Aircraft Part Database*

### **Automated Part Identification Capture System**

Recognizing that bar codes are not suitable for direct part marking, the National Aeronautics and Space Administration (NASA) established a team to work with industry to develop and test a machine-readable two-dimensional symbol designed to be applied to non-paper substrates. This 5-year effort resulted in selecting the Data Matrix™ symbol for use in NASA applications and provided proof that 2-D symbols are reliable and can be applied to most aerospace materials without impacting performance.

NASA findings spurred additional testing by the Department of Defense (DoD) and private industry that resulted in selecting the Data Matrix symbol for parts marking by the Automated Identification Manufacturers (AIM) and the American National Standards Institute (ANSI). Additional part marking standards quickly followed as the automotive, electronics, pharmaceutical, and aircraft industries adopted the symbol.



*Figure 2 - The Data Matrix Symbol Can Be Scaled To Fit The Part.*

### **Methods to Identify Small Parts**

The aerospace industry and DoD have relied heavily on the use of cast, forge or mold, engraving; electrical arc pencil; electrical-chemical etch; embossing; hot stamp; rubber ink stamp; stencil and silk screen; and vibration-etch and add-on tags for part identification marking. These marking methods, originally designed to apply human-readable markings, do not provide the fidelity required to successfully apply micro-size (1/32-inch to 15/64-inch square), high-density machine-readable symbols. Their manual operations also added to the large number of data transposition errors associated with paper based manufacturing systems.

Recognizing these weaknesses, the parts identification industry began to refine existing marking methods so that they could be utilized to apply 2-D symbols. The manual metal stamp and embossing technique methods were replaced by dot peen machines. Automated micro-profilers were designed to replace the manual cutting wheel used to produce paint stencils. Thermal printing materials were developed to replace the direct impact electro-chemical etch stencil materials, and ink jet machines were built to replace rubber-stamping. While these new methods provided the means to apply 2-D symbols directly to products, they did not provide the fidelity to produce micro-sized or high data density symbols. The laser marking systems designed to replace the electric-arc etch and hot stamp processes provide the necessary resolution, but were not being widely accepted in the aerospace industry. The impeding factors associated with this reluctance are:

- High cost in relation to other marking methods
- Perceived complexity of operations
- Large size and the need for special safety equipment
- Safety issues related to the heat affected zone generated in the marking area

In response to these concerns, laser manufacturers have begun to develop smaller and less expensive laser markers that are controlled by user-friendly windows-based software packages. Easy to operate portable laser marking units with safety enclosures are now being sold for less than \$46,000 (<http://www.lasermarking.net/start.html>).

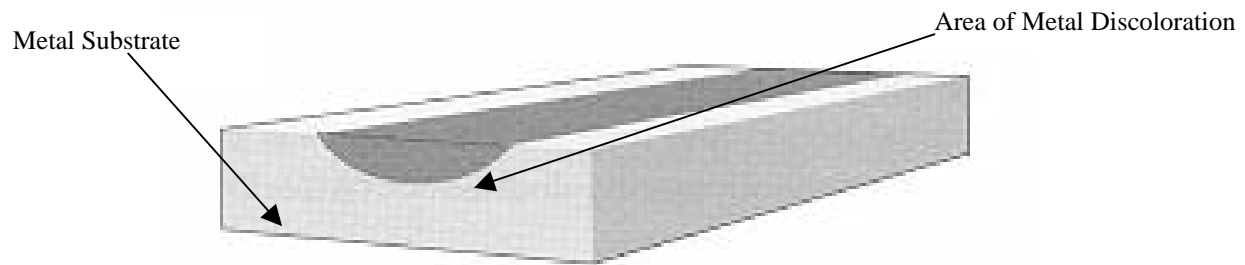
Many of the laser manufacturers, like Rofin-Sinar Technologies, Inc. (<http://www.rofin-sinar.com>), have incorporated test-marking programs into their software to speed the selection of optimum marking parameters that can be stored in a settings library for future selection. These actions have helped to close the gap between lasers and many of the other marking systems developed for use in industry. The perception that laser marking may not be safe in safety critical applications, however, remains.

### **Reduce Safety Risks Associated With Direct Marking**

The safety issues associated with laser marking are being addressed by CiMatrix's Symbology Research Center (SRC) through a Space Act Agreement with NASA's George C. Marshall Space Flight Center, Marshall Space Flight Center, Huntsville, AL (<http://techtran.msfc.nasa.gov>). These activities are being coordinated with the University of Tennessee Space Institute's Center for Laser Applications (<http://www.utsi.edu>) and other laser knowledge centers in the United States. This consortium has discussed laser marking with the aerospace industry and has noted a general lack of understanding of the various laser-marking processes currently available. The consortium also noted a general belief by most aerospace engineers that laser markings, produced by concentrating high heat to a small surface area, reduce material properties to an unacceptable level. This belief stems from material test reports that describe the propagation of cracks emanating from melted regions on the material surface. While lasers do mark using heat energy, it is not necessary to melt the substrate to produce machine-readable symbol markings. The precision controls available to laser operators provide a means to mark surfaces using many different methods. Many of these methods have minimal or no degrading effects on material properties. The following paragraphs of this paper address the various marking methods and techniques used by laser operators to mark parts and their general effects on the substrate:

### ***Laser Coloring***

Laser coloration is a process used to discolor metallic substrate material without burning, melting, or vaporizing the substrate material. This is done by passing a low power laser beam across a surface at slow speed to discolor the area of the mark. This laser marking method produces a high-quality, high-contrast marking that does not disrupt the surface. Laser colored markings will penetrate into deep surface imperfections, allowing the marking of surfaces with roughness levels up to 500 micro-inches. Laser coloring causes fewer surfaces disruption than the intrusive marking methods currently used to mark aerospace parts. The process, however, can have an adverse affect on materials that have been previously heat-treated and can reduce the corrosion resistant properties of some stainless steel alloys. These affects can be minimized or eliminated by using carefully selected laser marking parameters. Properly applied laser coloration markings applied to smooth surfaces cannot be felt when rubbed with the finger and appear smooth when viewed under low (10X) magnification. The laser coloring process is not recommended for parts thinner than 0.10-inch.



***Figure 3 – Marking Applied To A Surface Using the Laser Coloration Process***

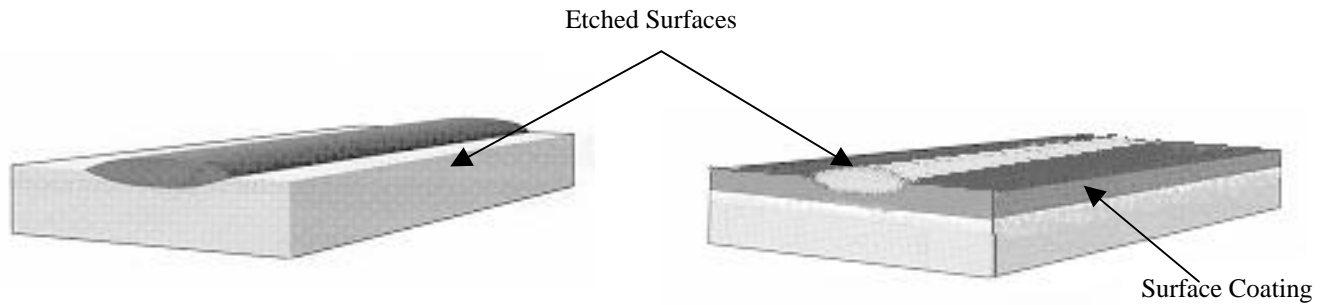
### ***Laser Etching***

Laser etching is similar to laser coloring except that the heat applied to the surface is increased to a level that causes substrate surface melting. The advantage to using this technique on metal over laser coloring is increased marking speed since the process requires less depth than is required to color metallic substrates. Excellent results can be routinely obtained at penetration depths of less than 0.001-inch. This technique, however, should not be used on some metals used in safety critical parts because cracks produced in the molten metal during cooling can propagate into the underlying surface material. These cracks can expand downward if the part is stressed and/or after repeated hot and cold cycles. These conditions have led to part failures.

Laser etching is frequently used to mark plastics that contain pigmented materials that are burnt off to produce striking color contrast. Additives supplied by companies such as the Sabreen Group, Inc., Plano, TX (<http://www.sabreen.com>), can be added to plastics that do not mark well to enhance contrast.

Laser etched marking can generally be felt when rubbed with a finger and have a corn row appearance when viewed under low (10X) magnification. Laser etching is not recommended for parts thinner than 0.050-inches in thickness.

Laser etching can be safely used in safety critical applications to mark coatings applied to substrates. The process, known in the industry as *Coat and Mark*, has been successfully demonstrated at the SRC using materials used to coat aircraft aluminum surfaces (AquaSurTech D-45 Grey Matt – <http://www.total.net/~aquasur>) and aircraft engine components subjected to temperatures up to 2000 degrees Fahrenheit (Duralco 200). Companies that manufacture pigments (or have patents on materials) that can be added to coatings to affect a color change when subjected to lasing include Ciba-Geigy Corporation; EM Industries, Inc.; InfoSight Corporation (<http://www.infosight.com>); Hanna M.A., Company; Kansai Paint KK; Merck; Merl; Nippon KK; and Quantum Chemical.



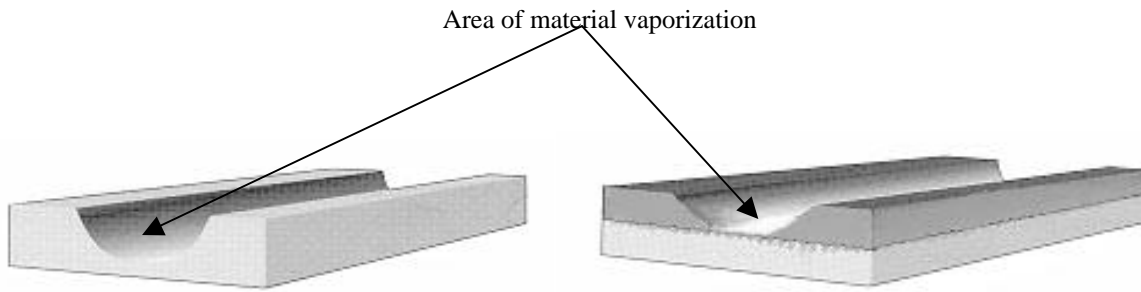
***Figure 4 – Laser Etching Applied Directly To A Surface***

***Figure 5 – Laser Etching Applied To A Surface Coating***

### ***Laser Engraving***

Laser engraving involves more heat than laser etching and results in the removal of substrate material through vaporization. This technique produces a deep light marking similar to a deep electro-chemical etch marking. The major advantage of this laser marking technique is speed, because it is the quickest laser marking that can be produced. The high contrast obtained by laser coloring or etching cannot be obtained by laser engraving because the discolored material is vaporized and ejected during the marking process. Although this method appears to be the most vigorous laser marking technique, it generally produces less damage to the substrate than laser etching. However, because it can produce micro cracking in some materials, its use in safety critical applications should be studied by a metallurgist prior to use. Like laser etching, direct laser engraving can be easily determined by touch and low power microscope (10X) magnification. Laser engraving is not recommended for use on parts less than 0.10-inches in thickness.

Laser engraving is acceptable for use in safety critical applications when used in conjunction with a *Coat and Remove* process. The *Coat and Remove* process involves the coating of a part with a media of contrasting color that is subsequently removed to expose the underlying material. The marking is as resilient as the surface coating used in the process.



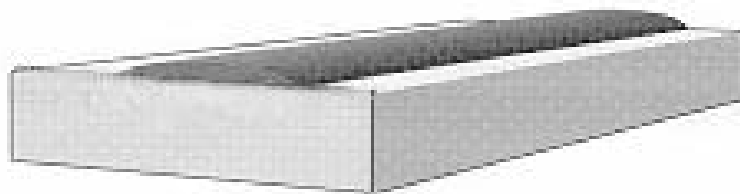
***Figure 6 – Laser Engraving Applied Directly To A Surface***

***Figure 7 – Laser Engraving Applied To A Surface Coating***

### ***Laser Bonding***

Laser bonding is an additive process that involves the bonding of a material to the substrate surface using the heat generated by a Nd:YAG, YVO<sub>4</sub>, or CO<sub>2</sub> laser. The proprietary materials, supplied by companies like Cerdec Corporation, Washington, PA (<http://www.cerdec.com>), generally consist of a glass frit powder or ground metal, oxides mixed with inorganic pigment, and a liquid carrier (usually water). The pigment can be painted or sprayed directly onto the surface to be marked, or transferred via pad printer, screen printer, or coating roller. Adhesive backed tapes coated with an additive are also used in this process.

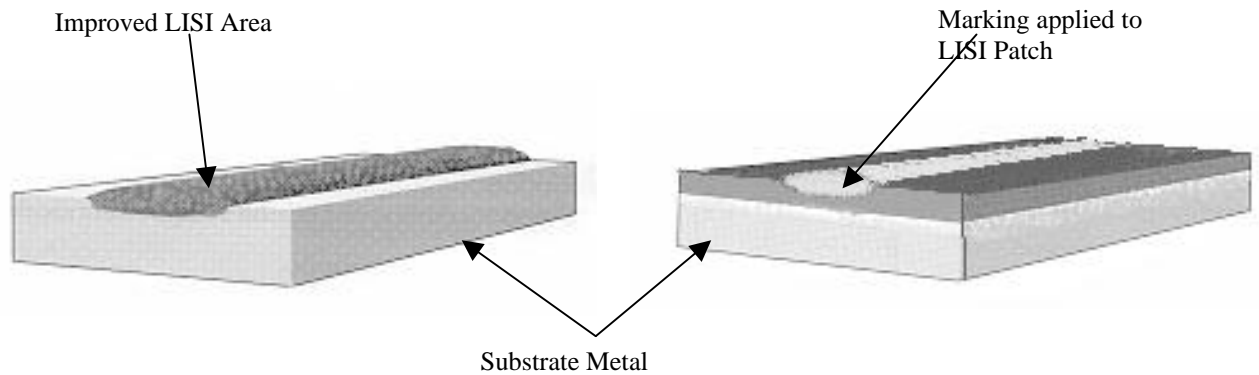
The process also can also be performed using a CO<sub>2</sub> laser and ink foils produced by Markem Corporation, Keene, NH (<http://www.markem.com>), for use in less harsh environments. Laser bonding is accomplished using heat levels that have no noticeable affect on metal or glass substrates and are safe for use in safety critical applications. The marking produced using this technique (dependant upon the material used), are resistant to high heat, are unaffected by salt fog/spray and are extremely durable.



***Figure 8 – Material Fused To A Surface Using The Laser Bonding Process***

### ***Laser Inducted Surface Improvement (LISI™)***

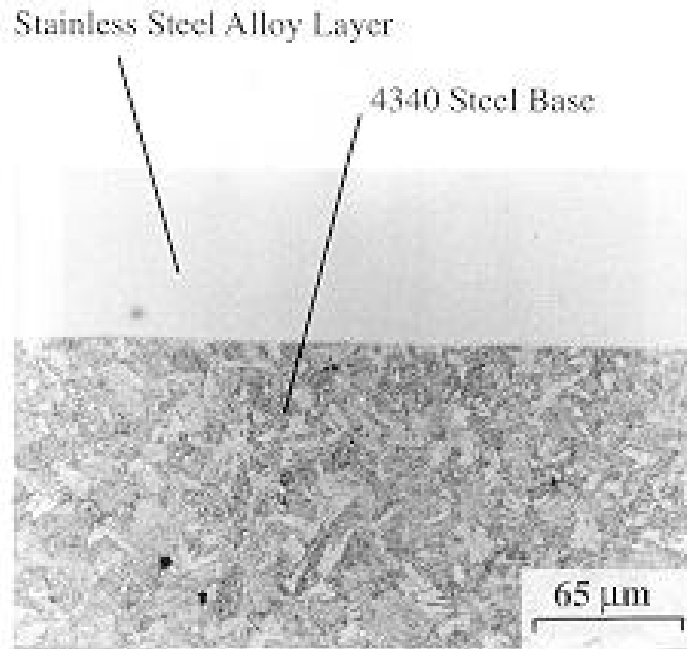
Laser induced surface improvement (LISI™) is similar to laser bonding except that the additive material is melted into the metallic host substrate to form an improved alloy with high corrosion resistance and wear properties. The LISI™ process and materials are proprietary (patents pending) and owned by the University of Tennessee Space Institute (UTSI), Tullahoma, TN. The materials are available from the Warren Paint and Color Company located in Nashville, TN and Cerdec Corporation in Washington, PA. The coating can be brushed or sprayed onto the surface and is marked after drying. The unmarked portions of the coating are subsequently washed off using tap water or a commercial cleaning agent. Symbol markings can be applied directly to the unimproved surface or to a LISI™ patch. The process works well on carbon steel and aluminum alloys.



***Figure 9 – LISI Marking Applied Directly To A Part Surface***

***Figure 10 – Laser Etched Marking Applied To A LISI Patch***

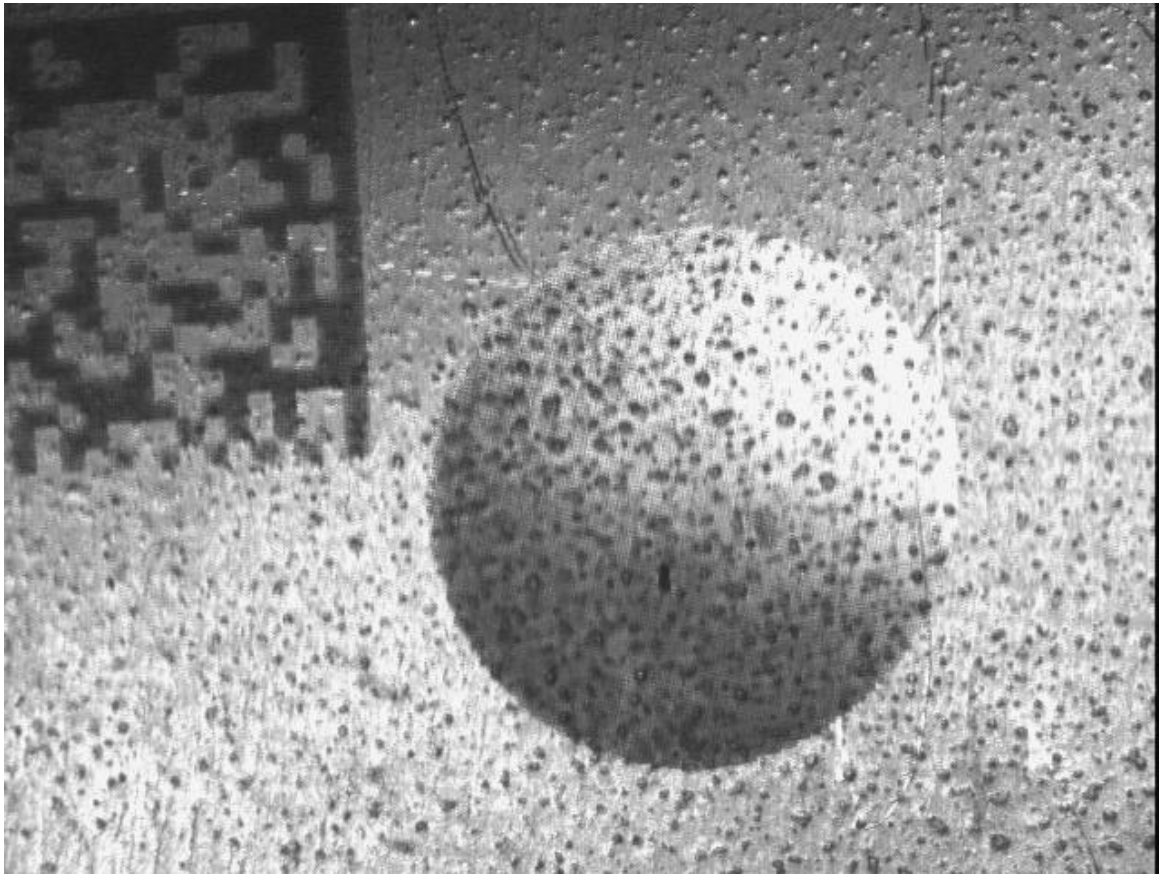




*Figure 11 – Scanning Electron Microscope View Of The LSI™*

#### ***Gas Assisted Laser Etch (GALE)***

Ambient environment laser marking often results in a limited degree of contrast between the engraved mark and the background on which it is placed. This can limit the speed of the mark and the number of different materials that can be marked. The gas-assisted laser etch (GALE) technique can be used to mark an object in the presence of a selected gaseous environment, thus enhancing contrast and increasing readability. The mark is made using low power settings, enabling the mark to be made with minimal laser interaction with the target material. GALE accomplishes this by the use of an assist gas that reacts with the material under the influence of the laser energy to produce a reactant that is a different reflective color from the background. The assist gases might be reducing, oxidizing or even inert, their selection being dependent upon the target material. A contrasting surface results at the coincident point of the laser, the gas and the material, producing a high contrast, readable mark created in a controlled environment. Tests performed at the University of Tennessee's Space Institute have demonstrated that the process should be safe for use in most aerospace marking applications.



*Figure 12 – View Of Gas Assisted Laser Etch Coating Under Magnification  
(Note That Surface Protrusions Are Left Intact After Marking)*

#### ***Laser Induced Vapor Deposition (LIVD)***

Laser induced vapor deposition is a proprietary process (patent pending) developed by CiMatrix's SRC that is used to apply part identification markings, heating and defrosting strips, antennas, circuitry, and sun shields to transparent materials. This is accomplished by vaporizing material from a marking media trapped under a transparent part using heat generated from a laser. The gaseous vapors and droplets resulting from the heat build up and condense on the cooler transparent surface to form a hard uniform coating that is applied in a prescribed pattern. The process is accomplished under normal office conditions without the need for high heat or seal gas/vacuum chambers. The marking materials (most metals) used to produce machine-readable symbols can be formulated to be read using both optical readers and sensing devices like X-ray, thermal imaging, ultrasound, magneto-optic, radar, capacitance, or other similar sensing means.



*Figure 13 – Stainless Steel Marking Applied To Glass Slide Using LIVD Process*

Other related laser processes are being jointly developed by the UTSI Center for Laser Applications (CLA) and CiMatrix's SRC. The LIVD processes will provide yet another safe way to apply machine-readable marking to aerospace parts. Details of these advanced processes will be reported in updates to this white paper in the future.

*Table 1 – Laser Marking Process Comparison Table*

| <b>Laser Marking Process Comparison</b> |   |                   |                      |                        |                        |                              |
|---|---|-------------------|----------------------|------------------------|------------------------|------------------------------|
| <b>Marking Process</b>                  | <b>Attributes</b>                           |                   |                      |                        |                        |                              |
|   | <b>Laser Type</b>                           | <b>Mark Power</b> | <b>Marking Speed</b> | <b>Marking Quality</b> | <b>Mark Durability</b> | <b>Removes Part Material</b> |
| Laser Coloration                        | Nd:YAG                                      | Low               | Slow                 | Excellent              | Excellent              | No                           |
| Laser Etching -Direct                   | Nd:YAG                                      | Medium            | Fast                 | Very Good              | Excellent              | Yes                          |
| Laser Etching – Coat and Mark           | CO <sub>2</sub> , LVO <sub>4</sub> & Nd:YAG | Low               | Two step process     | Excellent              | As durable as coating  | No                           |
| Laser Engraving – Direct                | Nd:YAG                                      | Medium            | Fast                 | Good                   | Excellent              | Yes                          |
| Laser Engraving – Coat and Mark         | Nd:YAG                                      | Low               | Two step process     | Excellent              | As durable as coating  | No                           |
| Laser Bonding                           | CO <sub>2</sub> , LVO <sub>4</sub> & Nd:YAG | Low               | Slow                 | Excellent              | Good                   | No                           |
| LISI™                                   | Nd:YAG                                      | High              | Slow                 | Good                   | Excellent              | No*                          |
| Gas Assisted Laser Etch                 | LVO <sub>4</sub> & Nd:YAG                   | Low               | Slow                 | Very Good              | Good                   | Minimal                      |
| LIVD™                                   | LVO <sub>4</sub> & Nd:YAG                   | Low               | Slow                 | Excellent              | Good                   | No                           |

\* Marked surface area has improved properties

### *Summary*

Advancements in laser technology are proceeding at a rapid rate and are providing users with a wide range of marking options. These include non-contact methods for applying high contrast, permanent marking to: 1) safety critical parts, 2) parts too small to mark using other marking processes, and 3) parts that are subjected to harsh manufacturing and use environments. Several new lasers are under development that will further reduce costs and improve product marking. For instance, Spectra Diode Labs (SDL) is developing a new compact, air-cooled fiber (the FLM1 - <http://www.sdli.com/products/systems/flm1.html>) that will reduce 5-year laser operating costs from \$140,000 to approximately \$17,500. Green lasers are being developed to mark delicate parts like silicon wafers without damaging the circuitry and blue, indigo and violet lasers are in work to further reduce marking size.

The CiMatrix SRC/UTSI CLA team is dedicated to helping government and industry to develop solutions to difficult marking and materials problems and in moving technology out of the laboratories and into the commercial market place. Specific questions can be directed to either facility at the following addresses:

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